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Energy Procedia 4 (2011) 29–34
Energy Procedia
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GHGT-10

Development of Carbon Dioxide Removal System from the Flue Gas of Coal Fired Power Plant

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Abstract

Post-combustion carbon dioxide capture is the technique that can be rapidly and safely employed for substantially reducing carbon dioxide emissions from existing and near future power plants. The key question of the absorption/desorption technique for carbon dioxide removal is process economics. Toshiba is pushing through the post-combustion carbon dioxide capture because it can be employed in rather short period and applied for both retrofit and new power plants.

In this work, we evaluated the seven amine-based absorbents as new solvents, which was selected from about 900 amines, in terms of energy consumption for CO_2 desorption using a thermodynamic absorption and desorption cycle simulation. We estimated the consumed energy in the stripper when the flue gas contains 12 % CO_2 and the capture ratio of CO_2 from the flue gas is 90 %. It was found that the lowest energy consumption in the stripper was about 2.5 GJ/t- CO_2 when one mixed amine-based aqueous solution (Toshiba Solvent 2, TS-2) was used as the solvent. The value was much lower than that for the general 30 wt. % monoethanolamine (MEA) aqueous solution. And it is lower than our former solvent (Toshiba Solvent 1, TS-1) which was presented at GHGT-9.

Then we evaluated the new solvent TS-2 using the bench-scale test facility which contains a complete absorption/desorption process with the absorber and the stripper. At this test TS-2 showed lower consumed energy, less than 2.5 GJ/t-CO_2, by optimizing the space velocity of the simulated flue gas and so on, while TS-1 showed about 2.7 GJ/t-CO_2 which is nearly equal of the value of the thermodynamic simulation.

Parallel to these activities the pilot plant of 10 t-CO_2/day recovery was constructed and commenced in September 2009 with a complete absorption/desorption supplied with the flue gas of a coal fired power plant. In the demonstration tests CO_2 capture ratio and captured CO_2 rate exceeded the planning values of 90% and 10t-CO_2/day each during continuous 3,000 hour operation. Furthermore the energy consumption for CO_2 recovery at the stripper had been kept between 3.2 and 3.3 GJ/t-CO_2. These results prove that Toshiba CO_2 capture system using TS-1 solvent is a promising system which has been realizing good and stable performances. Toshiba will utilize the results of these studies to further improve and optimize the performance of the system, towards implementation and integration of the system to a larger scale thermal power plant system.

Post combustion; CO_2 capture; amine; regeneration energy

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doi:10.1016/j.egypro.2011.01.019

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1. Introduction

The global warming resulting from anthropogenic carbon dioxide (CO_2) is one of the most important environmental issues. And a quarter of CO_2 emissions all over the world are exhausted from the thermal power plants. CCS is most effective technology for mitigating the vast amount of the greenhouse gas emissions and is expected to play the most important role. On the contrary, it is also anticipated that the technology will require a huge investment and operational costs, and therefore, more economical systems are strongly expected.

Toshiba has been supplying many efficient steam turbine cycles for thermal and nuclear power plants all over the world. For these years we also have been concentrating the development of more economical CO_2 capture technology for post-combustion to contribute to this global problem[1],[2].

We are pushing through the post-combustion carbon dioxide capture because it can be employed in rather short period and can be applied for both retrofit and new power plants. Toshiba will be able to supply the CCS installed thermal power plants by integrating power generation, flue gas treatment and CCS system. In order to realize near zero emission thermal power plants Toshiba is developing CCS technology along the roadmap shown in Fig.1.

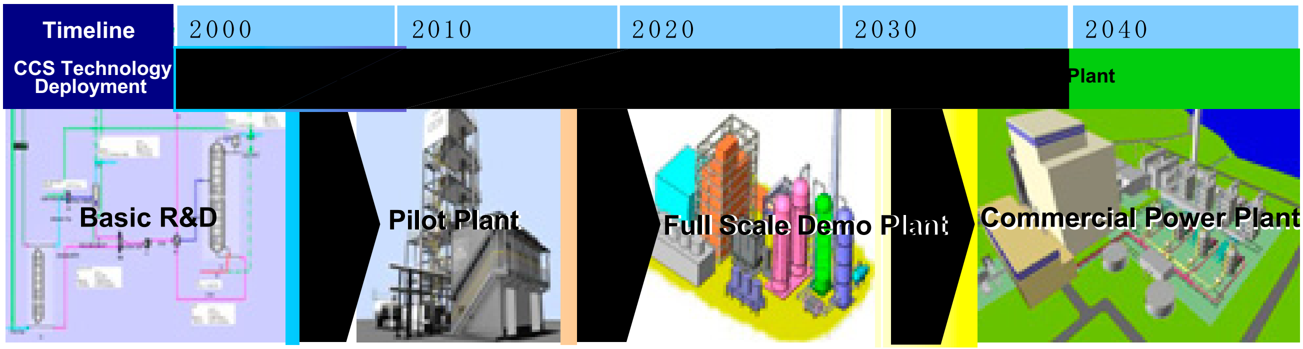

Fig.1 Roadmap towards Near Zero Emission Thermal Power Plant

2. Screening of solvents by thermodynamic simulation

In order to search for promising solvents, we carried out the thermodynamic simulations at the CO_2 absorption and desorption cycle shown in Fig.2 which includes an absorber, a stripper, and a lean/rich solvent heat exchanger. We estimated the consumed energy at the stripper under the conditions that the CO_2 concentration of the flue gas is 12 % and the CO_2 capture ratio from the flue gas is 90 %.

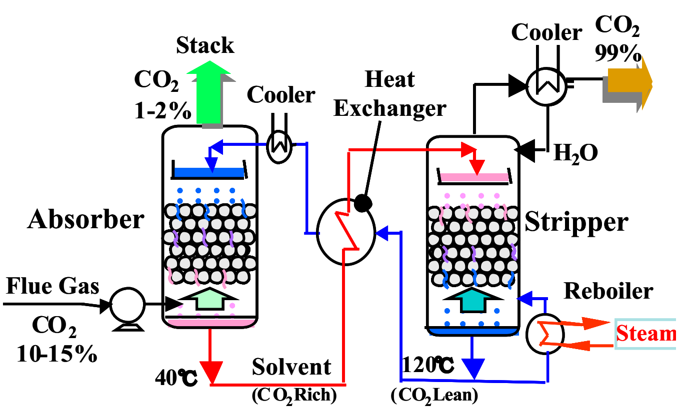

Fig.2 Flow Diagram of CO_2 Absorption and Desorption Cycle

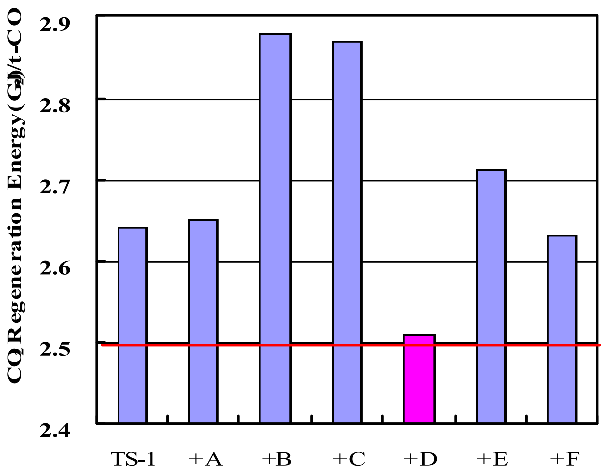

Fig.3 Results of Thermodynamic Simulations

We had already selected one promising solvent (Toshiba Solvent 1, TS-1) using this cycle from about 900 amine-based absorbents whose consumed energy is 2.6 GJ/t-CO_2, which is much lower than that of the general 30 wt. % monoethanolamine (MEA) aqueous solution.[2] At this time seven candidate solvents which are mixtures of TS-1 and an amine-based absorbent were evaluated. As shown in Fig.3 it was found that TS-1 mixed with an absorbent D (Toshiba Solvent 2, TS-2) was the lowest consumed heat in the stripper and its value became about 2.5 GJ/t-CO_2. Besides two mixed solvents showed about 2.6 GJ/t-CO_2.and other mixed solvents about 2.7 and 2.9 GJ/t-CO_2 each.

3. Evaluation of promising solvents by bench-scale test facility

As the next step of the screening by the simulations, evaluations using the bench-scale test facility shown in Fig.4 were performed. The test facility realizes a complete absorption/desorption process which has the absorber with the diameter of 160 mm and the height of 6,000 mm, and the stripper with the diameter of 200 mm and the height of 3,600 mm. A flue gas of coal-fired power plant was simulated by a mixture of air and CO_2 whose concentration is 12%. We optimized the space velocity of the simulated flue gas and the weight ratio of the solvent to the simulated flue gas in the absorber.

In Fig.5, TS-1 showed the lowest energy consumed in the stripper was about 2.7 GJ/t-CO_2 with 90 % CO_2 removal, which was nearly equal to the value, about 2.6 GJ/t-CO_2, predicted at the thermodynamic simulation. While TS-2 (TS-1 + absorbent D) showed lower consumed energy of less than 2.5 GJ/t-CO_2 when the minimum temperature difference between the hot CO_2 rich solvent which entered the stripper and the CO_2 lean solvent entered the lean/rich heat exchanger is 5 K This condition, 5 K, is same as that of TS-1 and is achievable at the 10 t-CO_2/day pilot plant to be described in the next chapter. The consumed energy in the stripper depended strongly on the temperature difference. Results of the effect of increased temperature difference between 5 K and 10 K is shown in Fig.5.

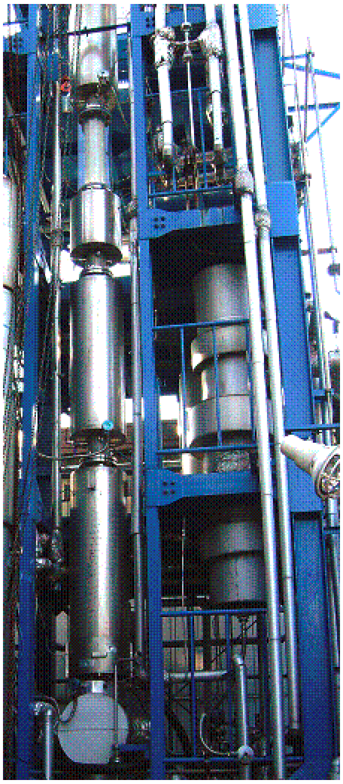

Fig.4 Bench-scale Test Facility

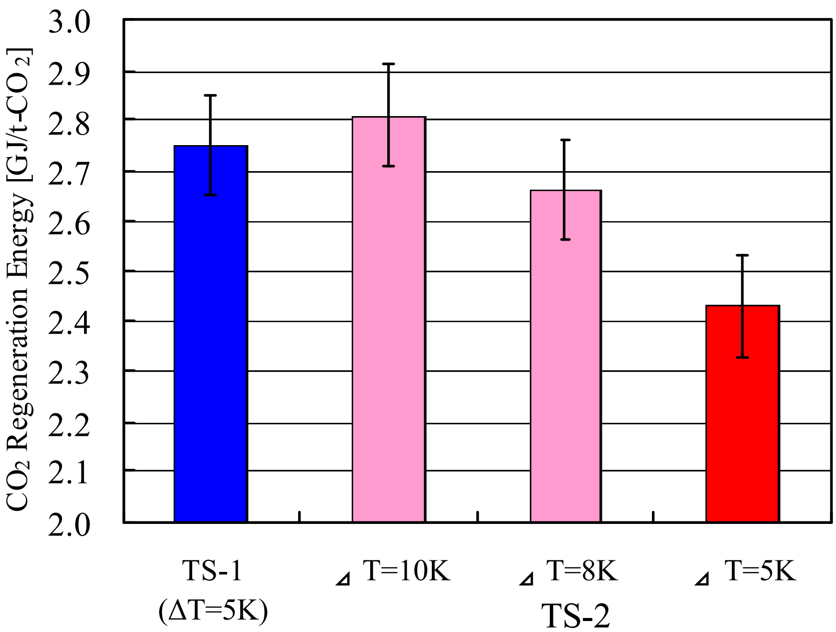

Fig.5 Test Results of Bench-scale Test Facility

4. Demonstration of CO_2 Capture from the Flue Gas of a Coal-Fired Boiler

In September 2009, we have completed a 10 t-CO_2/day pilot plant, which introduces and works on the flue gas from the Mikawa coal fired thermal power plant located in Fukuoka, Japan. (Fig.6)

Fig.6 Location of the 10t-CO_2/day Pilot Plant

The appearance of the plant is shown in Fig.7 and the plant specification is shown in Table 1.

Fig.7 Apperance of the 10t-CO_2/day Pilot Plant

Table 1 Pilot Plant Specification

Location	Mikawa Thermal Power Plant SIGMA POWER Ariake Corp.
Source Gas	Flue Gas of Coal-Fired Boiler
Treated Gas Flow Rate	2100Nm^3/h
CO_2 Concentration	Approx. 12%
CO_2 Capture Ratio	90%
Captured CO_2	10t-CO_2/day
Impurities	SOx, NOx, Dust, etc
Solvent	TS-1 Solvent

The flow diagram of the pilot plant is shown in Fig8. The flue gas of the power plant is introduced at the downstream of the existing FGD and supplied to the absorber via the additional FGD which remove most of the SO_2 in the flue gas. At the outlet of the stripper the steam contained in the treated gas is removed by the condenser and almost pure CO_2 gas can be obtained.

Now it has been operating continuously using the flue gas from the coal-fired power plant and the cumulative operating time reached close to 4,000 hours. During this period, stable operations and the better performances of the CO_2 capture than those of the planning has been maintained.

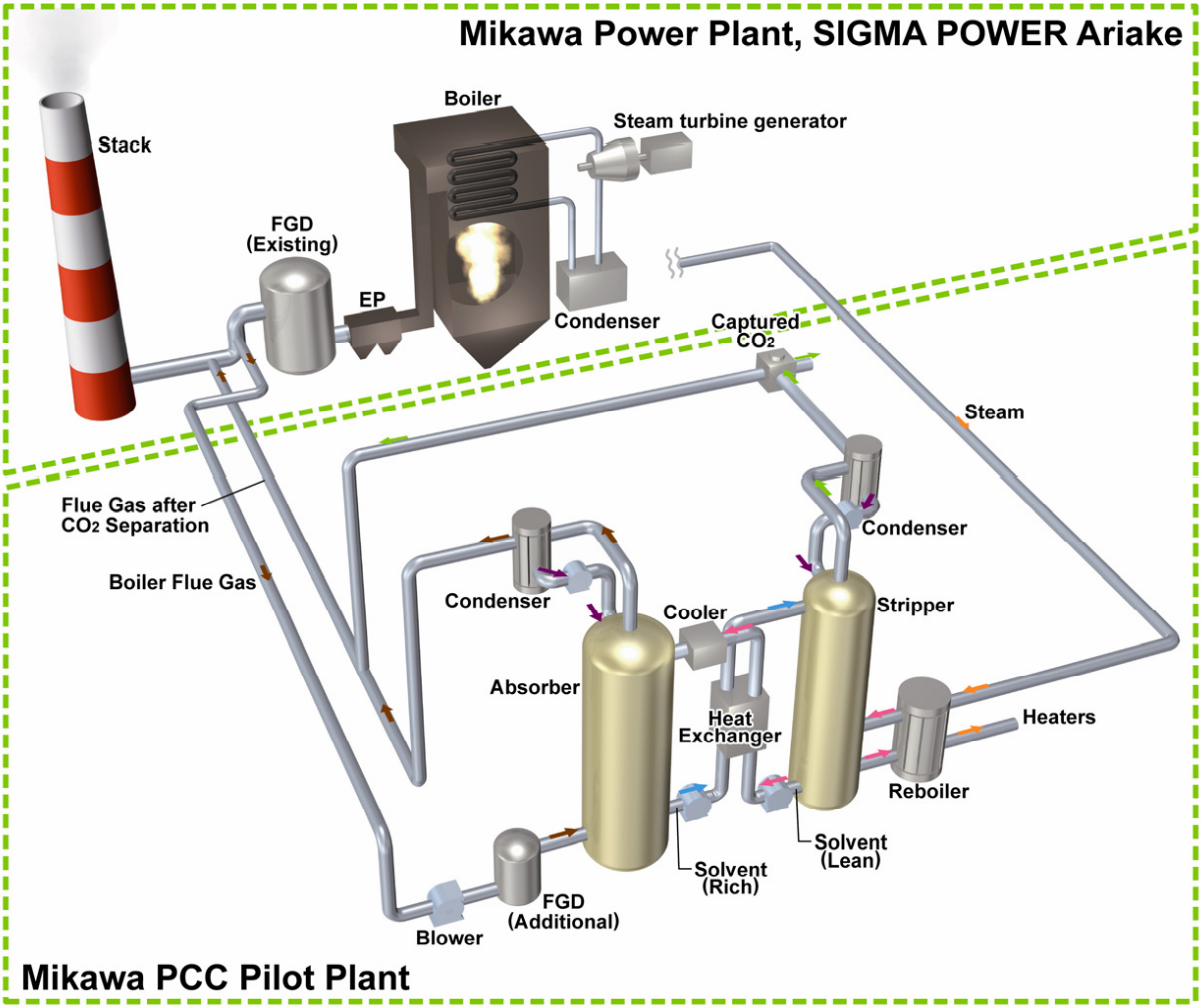

Fig.8 Flow Diagram of the 10t-CO_2/day Pilot Plant

As shown in Fig.9, CO_2 capture ratio and captured CO_2 rate exceeded the planning values of 90 % and 10t-CO_2/day each during continuous 3,000 hour operation. Fluctuations of these values in Fig.9 are due to those of the CO_2 concentration of the flue gas from the Mikawa power plant at the absorber inlet. Furthermore the energy consumption for CO_2 recovery at the reboiler had been kept between 3.2 and 3.3 GJ/t-CO_2.

On the other hand the concentrations of degraded substances, such as ions of several organic acids, sulphate, sulphite, nitrite and so on, had been increasing within TS-1 solvent because of the degradation by the oxygen, SOx and NOx in the flue gas. But no corrosion has been found in the equipments and pipes using stainless steel materials inside the system after 3,000 hour operation.

These results prove that Toshiba CO_2 capture system using TS-1 solvent is a promising system which has been realizing good performances and not degraded during its continued operations under actual live flue gas.

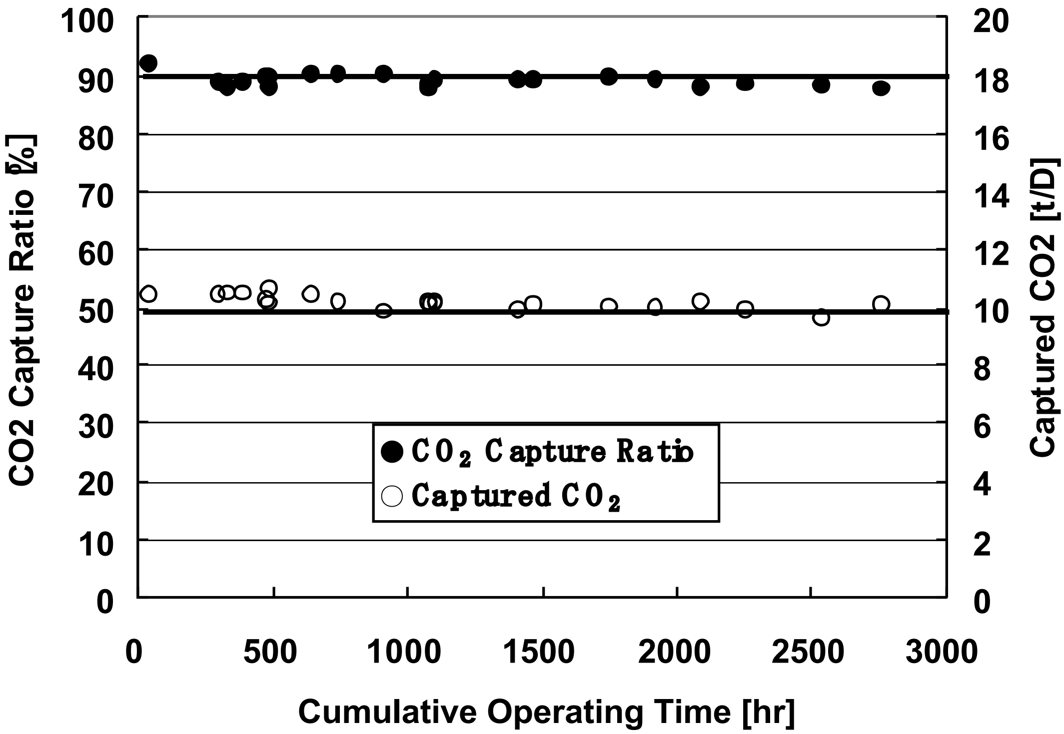

Fig.9 Performances of the CO_2 Capture at the10t-CO_2/day Pilot Plant

5. Conclusions

We have found a novel and promising amine-based absorbent by the thermodynamic simulations and proved at the bench scale test facility. We have also constructed and commenced operation of a 10 t-CO_2/day pilot plant using the flue gas from the coal fired power plant, which is demonstrating good performances during continuous 3,000 hour operation.

We will continue to further improve performance of the system towards lower energy consumption, by implementation of more advanced amine solutions found through R&D screening, and by optimization of the system, both which can be tested and verified at the pilot plant.

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